

**Anomalies of Larval and Juvenile Shortnose and Lost River Suckers
in Upper Klamath Lake, Oregon**

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Abstract.—Larval and juvenile shortnose (*Chasmistes brevirostris*) and Lost River (*Deltistes luxatus*) suckers from Upper Klamath Lake, OR, were examined to determine anomaly rates for fins, eyes, spinal column, vertebrae, and osteocranium, and their possible associations with water quality and pesticides. X-rays of 1,550 fish and 1,395 matching specimens, collected in 1993, were ranked on the severity of anomalies. One or more anomalies were observed in 15.9% of shortnose suckers and 8.2% of Lost River suckers. Anomaly rates exceeding 1.0%, greater than rates expected from high water quality systems, were observed for lordosis and scoliosis, and abnormalities of the vertebrae, opercula, and pectoral and pelvic fins in shortnose suckers, and abnormalities of vertebrae and opercula in Lost River suckers. The highest rates of anomalies were in vertebrae, pelvic fins, and opercula in shortnose suckers, and opercula and vertebrae in Lost River suckers. Shortnose suckers exhibited higher rates than Lost River suckers for almost all anomalies. Particular anomaly rates differed significantly among sites. There were also substantially more anomalies found in larvae and small juveniles than in larger juveniles. Based on the high anomaly rates observed in this study, it is possible that 0-aged sucker cohorts in Upper Klamath Lake are far more vulnerable to mortality.

Introduction

Upper Klamath Lake in south-central Oregon is the seventh largest lake in the United States and the largest lake in surface area in the Pacific Northwest, providing critical habitat for two species of endangered suckers, the shortnose sucker (*Chasmistes brevirostris*) and the Lost River sucker (*Deltistes luxatus*).

In 1991–1992 surveys, Littleton (1993) identified high external anomaly rates (including parasitism, discoloration, and lesions) in 37–73% of adult fish, primarily fathead minnows (*Pimephales promelas*) and chub species (*Gila* spp.), in the Upper Klamath Basin. In concurrent studies using water from the same sites sampled by Littleton, very high rates of amphibian developmental deformities and acute toxicity were demonstrated in frog bioassays (Boyer 1993). The finding of both fish and amphibian deformities is suggestive of ongoing ecosystem-wide water quality and/or contaminant impacts.

Recent surveys by the Bureau of Reclamation Area Office, Klamath Falls (Reclamation), the Klamath Tribes, and the Biological Research Division of the U.S. Geological Survey (USGS) have also disclosed high rates of anomalies in endangered suckers of Upper Klamath Lake, including blindness, cataracts, scoliosis, crooked and bent peduncles, missing or abnormally sized fins (including missing lobes of the caudal fin), skin tumors, and missing or shortened opercles (not covering the gills). Perkins (U.S. Fish and Wildlife Service, unpublished data) reported the prevalence of afflictions for adult shortnose and Lost River suckers collected in April and May 1996–98 from the Williamson River, OR. Fin afflictions ranged from 4–8% for shortnose suckers and 1–10% for Lost River suckers, while spinal, cranial, facial, and opercular anomalies ranged from 1–4% for shortnose suckers and 1–2% for Lost River suckers.

Extremely poor water quality has repeatedly been demonstrated to occur within the Upper Klamath Basin, including Upper Klamath Lake, as a result of very high concentrations of toxic unionized ammonia and pH, high water temperatures, and very low dissolved oxygen concentrations during the summer (Hazel 1969; Bortleson and Fretwell 1993; Gearheart et al. 1995; Simon et al. 1995; Laenen and LeTourneau 1996; Wood et al. 1996; Snyder and Morace 1997; Kann and Walker 1999). This study was performed to rigorously examine anomaly rates of larval and juvenile Lost River and shortnose suckers in various areas of Upper Klamath Lake and to evaluate whether anomaly rates could be related to water quality or pesticides.

Study Area

Lost River and shortnose sucker specimens were periodically collected from 25 locations in Upper Klamath Lake from 12 July 1993 through 19 October 1993 (Figure 1). The 31,000-ha lake is located in southcentral Oregon, extending from Agency Lake at its northern end to Klamath Falls at its southern end. Most of the lake is 1–3 m in depth, with a trench system along the western side of the lake ranging from 4–14 m in depth. Sites 1 (Goose Bay) and Site 3 (adjacent to Hagelstein Park) are both subjected to farm runoff, including pesticides, and Site 3 is also subjected to pesticide use along the railroad. Site 2 receives irrigated drainwater from Modoc Irrigation District, which has comparatively good water quality, light cattle use, and no known pesticide use. Site 4 (Howard's Bay) is near heavily grazed, flood-irrigated land, and water is highly nutrient enriched and often anoxic.

Materials and Methods

Dr. Douglas Markle, Department of Fisheries and Wildlife at Oregon State University (OSU), provided the 1,395 specimens and 43 radiographs with x-rays of the 1,550 suckers used in this study. The standard lengths (SL) of preserved fish ranged from 14–85 mm for shortnose suckers, and 15–110 mm for Lost River suckers. Small seines, cast nets, and trawls were used for collection, and fish were placed in 95% ethanol on site. Within two months of collection, fish were x-rayed from a lateral aspect using a Faxitron cabinet x-ray machine and industrial grade film. The number of specimens on a radiograph ranged from approximately 10-100 fish, depending on specimen size. After conducting meristic studies, the data, specimens, and radiographs were forwarded to the authors of this study.

Specimens were ranked for health anomalies related to: (1) skeletal alignment and vertebrae, (2) fins, (3) osteocranium, and (4) eyes. Key skeletal anomalies were: 1) kyphosis, typically a convex curvature of the spinal column in the thoracic region creating a “humpback” appearance; 2) lordosis, a concave curvature of the spinal column in the lumbar region; 3) scoliosis, abnormal lateral curvature of the spinal column; and 4) the condition of individual vertebrae (e.g., constricted, enlarged, or other abnormality). Ranked osteocranial features included: 1) opercula conditions, and 2) pughead, missing or deformed bones in the maxillary region. Missing eyes were noted. In addition, we compared the number of digenetic trematodes between species and among sites and months from data supplied by OSU. However, parasitism was not included in quantification of anomaly rates. The system used to rank anomalies was adapted from Goede and Barton (1990) and Herman (1990) (Table 1).

Radiographs were used to inspect vertebrae and caudal bones, and to evaluate questionable anomalies observed in preserved specimens. Curvatures in spinal columns with no

evidence of a distinct bend or “kink” in the radiograph were deemed artifacts of preservation and/or rigor mortis, and not scored as anomalies.

We examined 1,183 shortnose suckers and 367 Lost River suckers. Due to the small size of most specimens, radiographs and specimens were examined using a 40X-dissecting microscope. Specimen size/developmental stage was a constraint in ranking some specimens for certain conditions. Many specimens with a standard length (SL) of ≤ 19 mm were still in the larval–juvenile developmental stage and had underdeveloped anal, dorsal, pelvic, and pectoral fins; therefore, fish ≤ 19 mm were not ranked for these fins anomalies. Also, missing specimens and specimens with a SL of < 17 mm were only evaluated for anomalies detectable in radiographs. Inconclusive conditions (e.g., due to poor radiograph quality) were not ranked, nor were abnormalities attributed to physical damage (e.g., from predation). The number of specimens examined for each anomaly is summarized in Table 2.

We used size quartiles to evaluate whether anomalies were more prevalent in younger, smaller fish, indicating possible genetic origin, or whether anomalies were developed later in life, indicating potential environmental influences. For evaluations of differences in anomaly rates among sites and in relation to water quality, we grouped sample sites in close proximity to one another. Four of the grouped sites (Figure 1) had adequate sample sizes of shortnose suckers for among-site comparisons ($N \geq 50$). The samples collected from these sites constituted approximately 90% of the shortnose sucker collection. Because of inadequate sample sizes, we did not make comparisons among sites for Lost River suckers. There were inadequate water quality data available for 1993; therefore, data for summer daytime conditions from 1994 to 1999 (Table 3), obtained from Reclamation, were used to illustrate some of the severe conditions that can occur in Upper Klamath Lake in the summer. Parameters considered in this study were

pH, water temperatures, and dissolved oxygen concentrations (DO). Two of our sites had no shoreline water quality data; therefore, we used water quality data from the nearest offshore location.

Statistical Analysis

Data were entered into Microsoft Excel 97 SR-2 spreadsheets and statistical analysis was conducted using SPSS v7.5.3 and Microsoft Excel 97 SR-2. The nonparametric Mann-Whitney U test was used to determine whether there were significant differences in anomaly rates between species. Pearson's bivariate correlation coefficient was used to determine correlations among possible interrelated anomalies. The nonparametric Kruskal–Wallis ANOVA and the Scheffe comparison tests were used to determine whether anomaly rates varied among sites, and if so, which sites differed significantly from one another. The same tests were used to determine the significance of anomaly rates through time (using month), and by size (using quartiles). The significance of differences in parasite loads between species was determined using a Student's t-test.

Results

At least 15.9% of shortnose suckers and 8.2% of Lost River suckers showed one or more anomalies. These rates may be conservative considering that not all features were observable for each fish. We found no significant correlations among any anomalies using bivariate correlation tests.

The individual anomaly rates notably higher than 1% in our study were vertebrae (8.0%), pelvic fin (4.3%), and opercula (2.7%) in shortnose suckers, and opercula (4.7%) and vertebrae (1.9%) in Lost River suckers (Table 2). When all types of spinal anomalies were combined, approximately 2.9% of shortnose suckers had one or more spinal anomalies. When all fin anomalies were combined, approximately 5.8% shortnose suckers and 2.1% Lost River suckers had one or more fin anomalies.

Most anomalies were ranked as slight (2), rather than moderate (3) or severe (4) (Table 2). Three anomalies: scoliosis, abnormal pelvic fins, and abnormal vertebrae differed significantly ($P \leq 0.05$) between species. Higher rates were observed in shortnose suckers for all but opercular and caudal and dorsal fin anomalies (Table 2).

Some anomaly rates differed significantly ($P \leq 0.05$) among size quartiles including lordotic, vertebral, and anal, pectoral, and pelvic fin anomalies in shortnose suckers, and opercular and vertebral anomalies in Lost River suckers (Table 4). To test the biological relevance and accuracy of using size quartiles, we performed the same tests using developmental stages. Results were almost identical to quartile results for shortnose suckers and there were insufficient data for Lost River suckers.

Of the shortnose sucker specimens examined, 783 (66%) had a $SL \leq 40\text{mm}$, whereas only 49 (13%) of Lost River suckers examined had a $SL \leq 40\text{mm}$. Due to such a disparity in specimen sizes, we believe results of species comparisons would be misleading, and therefore interspecies comparisons are not made.

Vertebral and lordotic anomalies varied significantly ($P \leq 0.05$) among months in this study (July through October). Vertebral anomaly rates peaked in July for both species, as did lordosis for Lost River suckers. However, the highest rates of lordosis occurred in September for

shortnose suckers. There were no consistent trends in anomaly rates for any particular anomaly from July to October. However, sample sizes varied considerably among sites and for different months, potentially affecting results.

Four anomaly rates, those for lordosis, scoliosis, and abnormal pectoral fins and vertebrae, varied significantly ($P \leq 0.05$) among sites for shortnose suckers (Table 5). Site 1 had the highest rate of lordosis and pectoral fin anomalies; Site 4 had the highest rate of scoliosis; and Site 3 had the highest rate of vertebral anomalies. One or more anomalies were found in 20.6% of fish collected from Site 3, 15.8% from Site 1, 13.5% from Site 4, and 4.7% from Site 2. Although other sites had insufficient sample sizes for comparison ($N < 50$), anomalies did occur, and rates ranged from 0–25%.

Digenetic trematode load varied significantly in shortnose suckers, with the highest rate (21.0%) occurring in the 3rd quartile. Load rates also varied significantly by month, peaking in August (mean = 0.93/fish), and by site, with Site 1 exhibiting the highest mean number of parasites/fish (0.83) and Site 4 exhibiting the lowest (0.0045). There were no significant correlations between anomaly rates and rates of digenetic trematode infection.

Discussion

Numerous causes of high deformity rates in fishes have been identified, including genetics, pollutants, water quality, nutritional deficiencies, infectious agents, and physical and electrical shocks (see reviews by Hickey 1972; McCann and Jasper 1972; Bengtsson 1975; Mayer et al. 1977; Couch 1979; Sindermann 1979; Baumann and Hamilton 1984; Lemly 1997; Brown and Núñez 1998).

However, the rate of deformities in fish populations in high quality waters is expected to be quite low. For example, Hughes and Gammon (1987) reported that anomaly rates of fish, including the largescale sucker (*Catostomus macrocheilus*) and the mountain sucker (*Catostomus platyrhincus*), averaged less than 1% in the upper Willamette River, OR, but approximately 6.5% in the lower river where contaminants and poorer water quality were identified. Similarly, in a four-year study, Lemly (1993) reported average anomaly rates of less than 1% for cyprinoids, including the white sucker (*Catostomus commersoni*), in two reference lakes, but an average rate of 20% in Belews Lake, NC, a lake contaminated by a power plant. Patten (1968) reported an anomaly rate of only 0.24% for 100,000 freshwater fish in Washington streams. These studies suggest that average anomaly rates are $\leq 1\%$ for high quality water systems, and rates $>1\%$ could be an indication of nongenetic influences, such as poor water quality or contamination. Although these rates maybe applicable to adult and subadult fish, no known studies have addressed “natural” anomaly rates in larval and juvenile fish.

Rates of genetic-based anomalies would be expected to be higher in younger cohorts than in older cohorts because of removal of anomalous fish from the population by selective pressures. Our tentative interpretation in this study is that those anomaly rates $\leq 2\%$ may be natural in very young fish, particularly when the highest rates occur among the smallest fish. Rates notably higher in the smallest, youngest suckers in this study included vertebral and opercular anomalies. Vertebral anomalies in this size quartile were 24.1% and 6.5%, and opercular anomalies were 4.9% and 11.6% for shortnose and Lost River suckers, respectively. Reduction in numbers of both species could be resulting in inbreeding depression, consequentially resulting in higher anomaly rates. However, young fish may also be more sensitive to lower levels of contaminants than older fish, and thus exhibit higher anomaly rates

(Lemly 1997). Therefore, other factors, such as contaminants and poor water quality, should also be considered.

This study also identified spinal and fin anomalies that may have nongenetic causes, based on the fact that rates for these anomalies were often higher for fish in the larger size classes than for fish examined in the smallest size class. We researched electroshocking activities and permits authorized for Upper Klamath Lake, and concluded that electroshocking, known to cause spinal anomalies, was not a factor in this study. Also, we found no correlation between parasite load and physical anomalies.

Some potential causes of spinal anomalies include extremely high or rapidly changing water temperatures at critical phases of early development, low dissolved oxygen concentrations, high pH, or combinations of these factors (Bengtsson 1975; McCormick et al. 1977; Brown and Núñez 1998). McCormick et al. (1977) reported that three successive lots of white suckers (*Catostomus commersoni*) larvae reared at 15°C and subsequently transferred to 30°C for two weeks experienced 100% spinal deformities among survivors. Similarly, Brown and Núñez (1998) reported that an entire cohort of Hawaiian goby (*Awaous guamensis*) larvae experienced scoliosis when fertilized eggs were inadvertently warmed by 5°C over a period of one hour. Wentz et al. (1998) reported that sites with the highest anomaly rates (including parasites) in the Willamette Basin, OR, also had the highest maximum water temperatures and percent open canopies, poorest riparian quality, smallest riffle areas, and low dissolved oxygen concentrations.

In the summer, water temperatures of 24°C are common in the upper 2 m of Upper Klamath Lake, and temperatures ranging from below 17°C to higher than 27°C have been recorded in July (Reclamation, unpublished data; Martin and Saiki 1999). Dissolved oxygen concentration below 1.0 mg/L and pH values exceeding 10.38, both potentially lethal levels

(Kann and Smith 1999; Saiki et al. 1999), can also occur in Upper Klamath Lake (Reclamation, unpublished data). Water mass movement as fast as 228 m/h has been documented during high wind events in the lake (Hazel 1969). Therefore, drifting sucker larvae may be subjected to rapid changes in water qualities in a relatively short period of time during high wind events or when drifting into or within Upper Klamath Lake. Young suckers are also shore-line oriented, potentially exacerbating exposures to diurnal temperature fluctuations.

Effects resulting from pesticides, organic compounds, and other pollutants have been well documented in the past twenty-five years (Mayer et al. 1977; Couch et al. 1979; Lindesjö et al. 1994; Lemly 1997). In the Upper Klamath Lake watershed, USGS (1998) identified use of three highly leachable pesticides during 1990–1993 and 1995 that have been linked to skeletal/vertebral anomalies: trifluralin, diuron, and 2, 4-D. Couch et al. (1979) found the herbicide trifluralin to cause severe cases of vertebral dysplasia in young sheepshead minnows (*Cyprinodon variegatus*). Although only 10 acres of farmland surrounding Upper Klamath Lake have been reportedly treated with trifluralin, detections of trifluralin in drainage's of Upper Klamath Lake in 1992 (Bennett et al. 1996) suggest additional unreported trifluralin use was likely during the study period.

The herbicide/sterilant, diuron has been more intensively used. Diuron was applied yearly from hy-rail spray trucks from as early as 1990 to at least 1997 for weed control on the railroad tracks running along the eastern shoreline of Upper Klamath Lake (T.A. Mayer, Asplundh Railroad Division, personal communication), where vertebral anomaly rates were highest. Diuron is teratogenic at high doses and has been known to cause wavy ribs, extra ribs, and delayed bone formation in mammals (WSSA 1994; USNLM 1995), but has not yet been linked to fish anomalies. Another commonly used pesticide on irrigated farmlands adjacent to

Sites 1 and 3, is the phenoxy herbicide 2, 4-D. This herbicide is known to reduce vertebral collagen concentrations in fathead minnows (*Pimephales promelas*) and catfish (*Ictalurus punctatus*), potentially resulting in broken or deformed backbones (Mayer et al. 1977). In addition to extensive spring agricultural use as a pre-emergent herbicide, we also documented use for spot spraying along the railroad tracks immediately adjacent to the lake.

Another possible contaminant in Upper Klamath Lake is pentachlorophenol (PCP), used by wood treatment facilities in the area and known to cause degeneration of fins and opercula and malformation of the skull (Cleveland et al. 1982; Hamilton et al. 1986). Though most facilities are no longer operating, the potential for residual contamination from PCP and its metabolite, pentachloroanisole, still exists. Due to a lack of contamination data for 1993, it is difficult to determine what concentration levels were at the time of our study. However, in studies conducted since 1995, only trace elements of PCP and organochlorine compounds have been detected and those detections were in an effluent canal to the lake (Snyder-Conn and Greenstein, USFWS, unpublished data; Toby Scott, Oregon Department of Environmental Quality, personal communication).

Of the anomaly rates differing significantly among sites, lordosis and pectoral fins were highest at Site 1; abnormal vertebrae was highest at Site 3; and scoliosis was highest at Site 4. All four sites have high summer pH levels exceeding 9.5, maximum temperatures exceeding 25°C, and dangerously low, possibly lethal, dissolved oxygen concentrations have repeatedly been observed at Sites 3 and 4.

Conclusion

This study identified high rates of deformities in larval and juvenile shortnose and Lost River suckers in Upper Klamath Lake. The anomalies described likely impair swimming, and could adversely affect feeding rates or avoidance of predators and adverse water quality conditions. The specific reason(s) for the high rates of anomalies we reported remain uncertain. Although vertebral and opercular anomalies could be genetic (mutational) in origin, based on their highest occurrences in the smaller suckers, other types of anomalies, including those of the spinal column and fins, which were often more prevalent in the larger size classes, do not fit the genetic hypothesis. Poor water quality and/or contaminants are also likely to contribute to the frequent high proportions of abnormal suckers in Upper Klamath Lake.

Further investigation of wood treatment, diuron, 2, 4-D, and trifluralin inputs in relation to fish deformity rates is warranted. We recommend that future studies include more than one year of sampling at several different sites on Upper Klamath Lake and at several reference sites, such as Clear Lake and Gerber Reservoir. Collection should include similarly sized fish of each species, water quality monitoring data, and spring and summer pesticide sampling.

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References

- Baumann, P.C., and S.J. Hamilton. 1984. Vertebral abnormalities in white crappie, *Pomoxis annularis* Rafinesque, from Lake Decatur, Illinois, and an investigation of possible causes. *Journal of Fish Biology* 25:25–33.
- Bengtsson, B.-E. 1975. Vertebral damage in fish induced by pollutants. Pages 23–30 in J.H. Koeman and J.J.T.W.A. Strick, editors. *Sublethal effects of toxic chemicals on aquatic animals*. Elsevier Science Publishing, Amsterdam.
- Bennett, J., and eight coauthors. 1996. Detailed study of water quality, bottom sediment, and biota associated with irrigation drainage in the Klamath Basin, California and Oregon, 1990–1992. Pages 19–47 in P.D. Dileanis, S.E. Schwarzbach, and J. Bennett, editors. *U.S. Geological Survey Water-Resources Investigations Report 95–4232*. Sacramento, California.
- Bortleson, G.C., and M.O. Fretwell. 1993. A review of possible causes of nutrient enrichment and decline of endangered sucker populations in Upper Klamath Lake, Oregon. U.S. Geological Survey, Water-Resources Investigations Report 93–4087, Portland, Oregon.
- Boyer, R. 1993. Evaluation of water quality in relation to frogs at Klamath Basin National Wildlife Refuges. M.S. thesis. University of Washington, Seattle, Washington.
- Brown, C.L., and J.M. Núñez. 1998. Disorders of development. Pages 1–17 in J.F. Leatherland

- and P.T.K. Woo, editors. Fish diseases and disorders, Volume 2: Non-infectious disorders. CAB International, New York, New York.
- Cleveland, L., D.R. Buckler, F.L. Mayer, and D.R. Branson. 1982. Toxicity of three preparations of pentachlorophenol to fathead minnows – a comparative study. *Environmental Toxicology and Chemistry* 1:205–212.
- Couch, J.A., J.T. Winstead, D.J. Hansen, and L.R. Goodman. 1979. Vertebral dysplasia in young fish exposed to the herbicide trifluralin. *Journal of Fish Diseases* 2:35–42.
- Gearheart, R.A., J.K. Anderson, M.G. Forbes, M. Osburn, and D. Oros. 1995. Watershed strategies for improving water quality in Upper Klamath Lake, Oregon. Humboldt State University Report, Volume 1, Arcata, California.
- Goede, R.W., and B.A. Barton. 1990. Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. *American Fisheries Society* 8:145–166.
- Hamilton, S.J., L. Cleveland, L.M. Smith, J.A. Lebo, and F.L. Mayer. 1986. Toxicity of pure pentachlorophenol and chlorinated phenoxyphenol impurities to fathead minnows. *Environmental Toxicology and Chemistry* 5:543–552.
- Hazel, C.R. 1969. Limnology of Upper Klamath Lake, Oregon with emphasis on benthos. Doctoral dissertation, Oregon State University, Corvallis, OR.
- Herman, R.L. 1990. The role of infectious agents in fish kills. Pages 45–56 *in* F.P. Meyer and L.A. Barclay, editors. Field manual for the investigation of fish kills. U.S. Fish and Wildlife Service Resource Publication 177. Washington, D.C.
- Hickey, C.R., Jr. 1972. Common abnormalities in fishes, their causes and effects. New York Ocean Science Laboratory Technical Report No. 0013, Montauk, New York.
- Hughes, R.M., and J.R. Gammon. 1987. Longitudinal changes in fish assemblages and water

- quality in the Willamette River, Oregon. Transactions of the American Fisheries Society 116:196–209.
- Kann, J., and V.H. Smith. 1999. Estimating the probability of exceeding elevated pH values critical to fish populations in a hypereutrophic lake. Canadian Journal of Fisheries and Aquatic Science 56:2262–2270.
- Kann, J., and W.W. Walker, Jr. 1999. Nutrient and hydrologic loading to Upper Klamath Lake, OR, 1991–1998. Report prepared for Klamath Tribes Natural Resource Department, Chiloquin, Oregon, and Bureau of Reclamation Cooperative Studies, Klamath Falls, Oregon.
- Laenen, A., and A.P. LeTourneau. 1996. Upper Klamath Basin nutrient-loading study: estimate of wind-induced resuspension of bed sediment during periods of low lake elevation. U.S. Geological Survey Open-File Report 95–414, Portland, Oregon.
- Lemly, A.D. 1993. Teratogenic effects of selenium in natural populations of freshwater fish. Ecotoxicology and Environmental Safety 26:181–204.
- Lemly, A.D. 1997. A teratogenic deformity index for evaluating impacts of selenium on fish populations. Ecotoxicology and Environmental Safety 37:259–266.
- Lindesjö, E., J. Thulin, B.-E. Bengtsson, and U. Tjärnland. 1994. Abnormalities of a gill cover bone, the operculum, in perch *Perca fluviatilis* from a pulp mill effluent area. Aquatic Toxicology 28:189–207.
- Littleton, T.M. 1993. Water quality and fishes of the Lower Klamath and Tule Lake National Wildlife Refuges. Masters thesis, University of Washington, Seattle, WA.
- Martin, B.A., and M. Saiki. 1999. Effects of ambient water quality on the endangered Lost

- River Sucker in Upper Klamath Lake, Oregon. Transactions of the American Fisheries Society 128:953–961.
- Mayer, F.L., P.M. Mehrle, and R.A. Schoettger. 1977. Collagen metabolism in fish exposed to organic chemicals. Pages 31–54 in R.A. Tubb, editor. Recent advances in fish toxicology: A symposium. Ecological Resources Serial Number EPA–600/3–77–085. U.S. Environmental Protection Agency, Corvallis, Oregon.
- McCann, J.A., and R.L. Jasper. 1972. Vertebral damage to bluegills exposed to acutely toxic levels of pesticides. Transactions of the American Fisheries Society 2:317–322.
- McCormick, J.H., B.R. Jones, and K.E.F. Hokanson. 1977. White sucker (*Catostomus commersoni*) embryo development, and early growth and survival at different temperatures. Journal of the Fisheries Research Board of Canada 34:1019–1025.
- Patten, B.G. 1968. Abnormal freshwater fishes in Washington streams. Copeia 2:399–401.
- Saiki, M.K., D.P. Monda, and B.L. Bellerud. 1999. Lethal levels of selected water quality variables to larval and juvenile Lost River and shortnose suckers. Environmental Pollution 105:37–44.
- Simon, D.C., D.F. Markle, and G.R. Hoff. 1995. Larval and juvenile ecology of Upper Klamath Lake suckers. Annual report of the Department of Fisheries and Wildlife, Oregon State University, to Klamath Project, U.S. Bureau of Reclamation, Klamath Falls, OR.
- Sindermann, C.J. 1979. Pollution-associated diseases and abnormalities of fish and shellfish: a review. Fishery Bulletin 76:717–749.
- Snyder, D.T., and J.L. Morace. 1997. Nitrogen and phosphorus loading from drained wetlands adjacent to Upper Klamath and Agency Lakes, Oregon. U.S. Geological Survey Water-Resources Investigations Report 97–4059, Portland, Oregon.

USGS (U.S. Geological Survey). 1998. Annual pesticide use maps.

<http://water.wr.usgs.gov/pnsp/use92/>

USNLM (U.S. National Library of Medicine). 1995. Hazardous Substances Databank.

Bethesda, Maryland.

Wentz, D.A., and nine coauthors. 1998. Water quality in the Willamette Basin, Oregon,

1991–95. U. S. Geological Survey Circular 1161, Portland, Oregon.

Wood, T.M., G.J. Fuhrer, and J.L. Morace. 1996. Relation between selected water-quality

variables and lake level in Upper Klamath and Agency Lakes, Oregon. U.S. Geological

Survey Water-Resources Investigation Report 96–4079, Portland, Oregon.

WSSA (Weed Science Society of America). 1994. Herbicide Handbook, 7th Edition.

Champaign, Illinois.

Table 1. Internal and external abnormality ranking system for Lost River and shortnose suckers from Upper Klamath Lake, 12 July 1993 – 19 October 1993 (adapted from Goede and Barton 1990, and Herman 1990).

Feature	Ranks			
	1	2	3	4
Spinal: (kyphosis, lordosis, scoliosis)	No abnormality	Slight curvature	Moderate curvature	Significant- extreme curvature
Opercula	No abnormality	Slight-moderate degeneration or deformity	Significant- extreme degeneration or deformity	One or both missing
Fins: (anal, pectoral, pelvic, dorsal, caudal)	No abnormality	Degenerated or clubbed <50%, or slightly deformed	Degenerated or clubbed 50 – <100%, or moderately- extremely deformed	One or both missing
Vertebrae	No abnormality	1–3 enlarged, degenerated, or other abnormal vertebra(e) in one locus	≥4 in one locus, or ≤4 in more than one loci	>4 and two or more loci
Eyes	No abnormality	One eye missing or hanging out of socket	Both eyes missing or hanging out of socket	-
Pugnose ^a	No abnormality	Slight deformity or one missing bone	Moderate deformity or two missing bones	Severe deformity or 3 or more missing bones
Parasites were ranked by #parasites/fish				

^a pertinent bones are maxillary, pre-maxillary, kinethmoid, and second pre-ethmoid

Table 2. Ranks and rates of anomalies for shortnose and Lost River suckers from Upper Klamath Lake, 12 July 1993 – 19 October 1993.

Anomaly	Shortnose						Lost River					
	Examined	ranks				Anomalous (%)	Examined	ranks				Anomalous (%)
		1	2	3	4			1	2	3	4	
Kyphosis	1,174	1167	6	1	0	0.6	366	366	0	0	0	0.0
Lordosis	1,175	1159	11	3	2	1.4	365	363	2	0	0	0.5
Scoliosis ^a	1,168	1151	15	2	0	1.5	361	361	0	0	0	0.0
Vertebrae ^a	1,139	1048	53	38	0	8.0	361	354	6	1	0	1.9
Anal fin	795	790	5	0	0	0.6	327	326	1	0	0	0.3
Caudal fin	1,146	1143	3	0	0	0.3	364	362	2	0	0	0.5
Dorsal fin	795	793	1	1	0	0.3	327	325	2	0	0	0.5
Pectoral fin	793	782	10	1	0	1.4	322	321	1	0	0	0.3
Pelvic fin ^a	795	761	29	4	1	4.3	326	325	0	0	1	0.3
Eyes	1,042	1039	3	0	N/A	0.3	319	319	0	0	N/A	0.0
Opercula	1,039	1011	19	9	0	2.7	317	302	5	10	0	4.7
Pughead	1,178	1174	2	0	2	0.3	366	366	0	0	0	0.0

^a differed significantly between species ($P \leq 0.05$)

Table 3. Daytime summer water quality for study sites in Upper Klamath Lake, OR, 1 June – 30 September 1994–1999.

Location	N	Water Quality Parameters		
		Low DO (mg/L)	High pH	High water temp (°C)
Site 1 ^a	37	4.28	10.12	25.8
Site 2 ^a	58	2.01	10.16	26.4
Site 3	1680	0.86	10.21	27.1
Site 4	2281	0.00	10.03	30.1

^a values are not from shoreline and are from 1998 only

Table 4. Anomaly rates by standard length quartiles (mm) for shortnose and Lost River suckers from Upper Klamath Lake, 12 July 1993 – 19 October 1993.

Anomaly	Quartiles							
	shortnose				Lost River			
	1 st	2 nd	3 rd	4 th	1 st	2 nd	3 rd	4 th
	(18.2) %	(24.2) %	(46.6) %	(84.8) %	(70.0) %	(75.5) %	(79.5) %	(110.3) %
Kyphosis	1.3	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Lordosis ^b	0.0	0.0	4.4	0.7	2.2	0.0	0.0	0.0
Scoliosis	1.7	1.0	2.7	0.3	0.0	0.0	0.0	0.0
Vertebrae ^{b,c}	24.1	6.0	0.0	1.0	6.5	0.0	1.1	0.0
Anal fin ^b	0.0 ^a	2.0	0.3	0.0	0.0	1.1	0.0	0.0
Caudal fin	0.0	0.0	0.7	0.4	1.1	0.0	0.0	0.0
Dorsal fin	0.0 ^a	0.0	0.7	0.0	0.0	1.1	1.1	0.0
Pectoral fin ^b	0.0 ^a	3.9	0.7	0.3	0.0	1.1	0.0	0.0
Pelvic fin ^b	0.0 ^a	5.4	6.2	1.7	0.0	0.0	1.1	0.0
Eyes	1.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Opercula ^c	4.9	2.2	3.1	1.4	11.6	6.5	3.2	1.1
Pughead	0.3	0.0	0.7	0.4	0.0	0.0	0.0	0.0
Parasites	11.4	17.8	37.4	17.3	4.3	3.3	4.3	3.3

^a not examined for respective anomaly

^b differed significantly in shortnose suckers ($P \leq 0.05$)

^c differed significantly in Lost River suckers ($P \leq 0.05$)

Table 5. Anomaly rates (%) for shortnose suckers by site in Upper Klamath Lake, 12 July 1993 – 19 October 1993 (number of samples examined in parentheses).

Location	Anomaly			
	lordosis ^a	scoliosis ^a	pectoral fin ^a	vertebrae ^a
Site 1	3.3(366)	2.7(365)	2.2(357)	0.6(340)
Site 2	0.0(192)	0.0(192)	0.0(178)	2.1(191)
Site 3	0.0(422)	0.5(419)	0.0(140)	17.9(414)
Site 4	0.0(87)	3.6(84)	0.0(42)	8.1(86)

^a differed significantly among sites ($P \leq 0.05$)

List of Figures

Figure 1. Map of study area showing sample sites (■) and groupings of sample sites (1–4).

